

# **AIR FORCE APPLICATION OF ADVANCED MAGNETIC MATERIALS**

**DARPA WORKSHOP ON METAMATERIALS  
GREENBELT, MARYLAND**

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# Outline



- More Electric Aircraft



- Unmanned Combat Air Vehicle (UCAV)



- Directed Energy Weapons

- Summary



# Propulsion Directorate

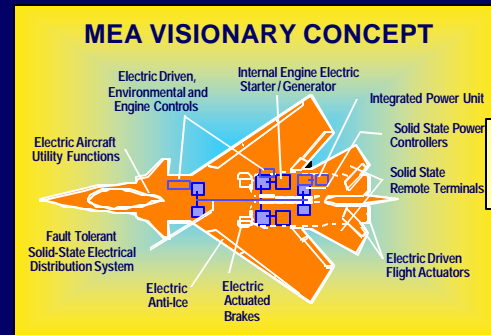


## Propulsion & Power for the 21st Century Warfighter





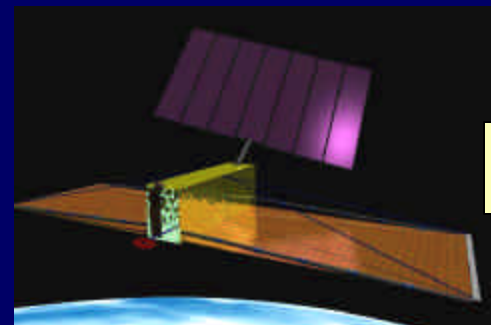
# Power Division Four Focus Areas



**AIRCRAFT**



**WEAPONRY**



**SPACECRAFT**



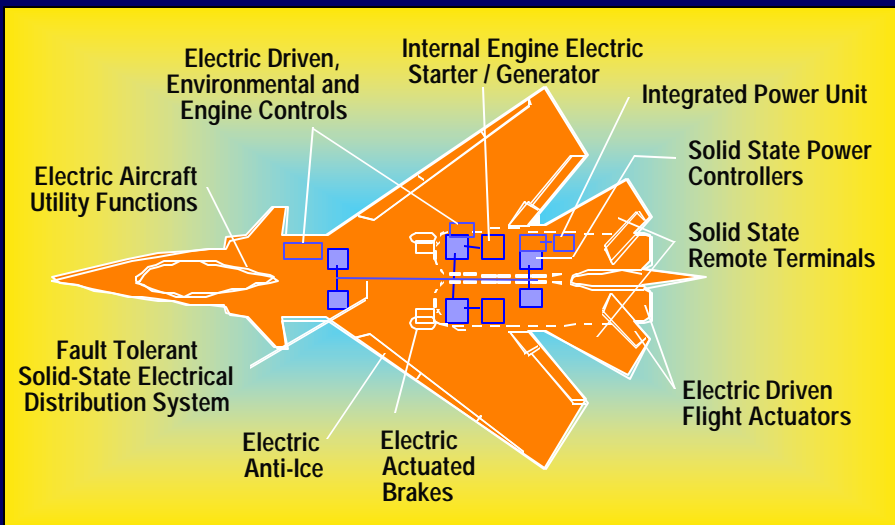


# More Electric Aircraft

## THE VISION



## THE IMPACT



- ALL-ELECTRIC AIRCRAFT (NO HYDRAULICS OR BLEED AIR PNEUMATICS)
- ELIMINATION OF ACCESSORY DRIVE GEARBOX (REDUCED FRONTAL AREA)

**ENABLES MISSION AVAILABLE POWER FOR LETHAL AIRBORNE DIRECTED ENERGY WEAPON**

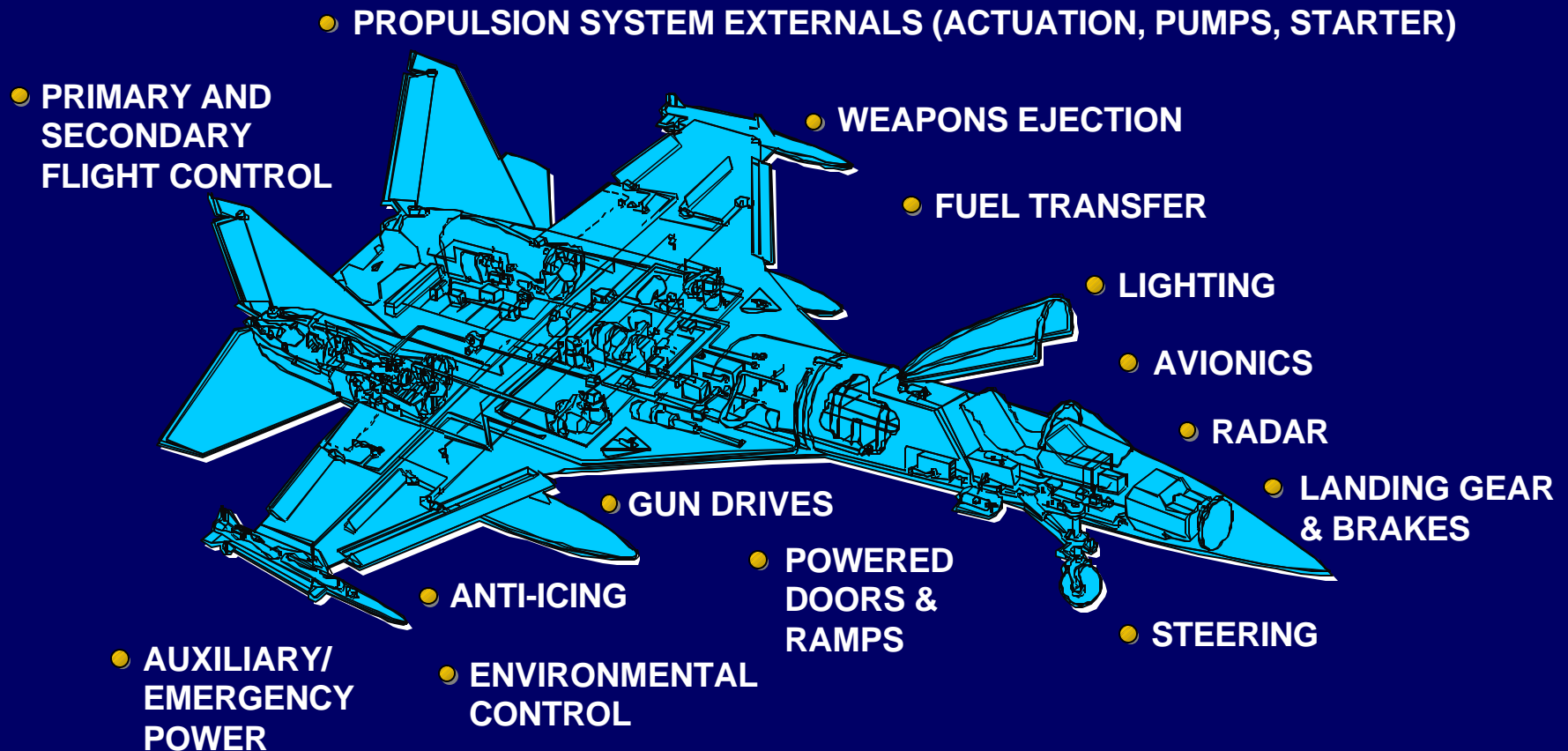
- REDUCED LCC
- DRAMATIC IMPROVEMENT IN R, M, & S
- REDUCED DEPLOYMENT FOOTPRINT AND MANPOWER
- INCREASED SORTIE GENERATION RATE

**SAVINGS IN \$B\$ WITH IMPROVED WARFIGHTING**

1992 LMTAS, 1995 VITPS, & 1998 J/IST STUDIES



# Conventional Non-Propulsive Aircraft Power



**A COMPLEX, HEAVY, HIGH MAINTENANCE HYBRID OF MECHANICAL, HYDRAULIC, PNEUMATIC AND ELECTRICAL SUBSYSTEMS**

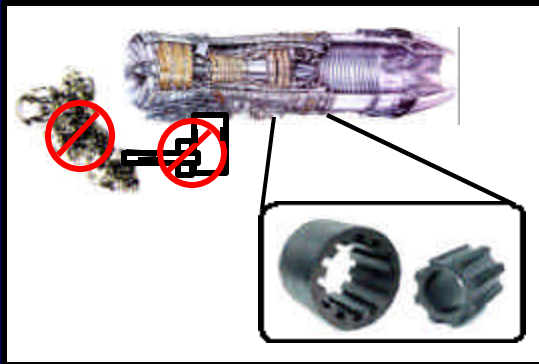


# Key MEA Technologies

- **TRANSITION TO ELECTRICALLY DRIVEN CONCEPTS DEPENDS ON DEMONSTRATION OF FOUR KEY SUBSYSTEM TECHNOLOGIES**

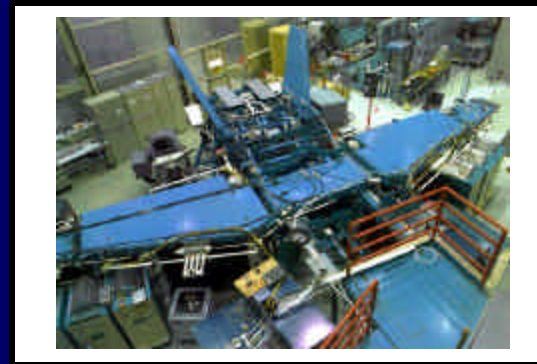
## INTERNAL INTEGRAL STARTER / GENERATOR

- Eliminates Gearbox
- More Electric Engine FY05-07



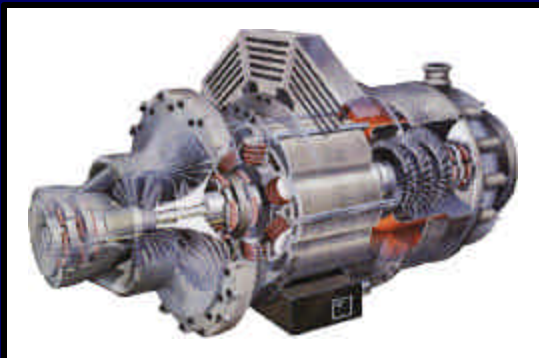
## FAULT-TOLERANT DISTRIBUTION

- Redundant/Reliable Electric Power
- Flight Worthy Hardware FY03-05



## INTEGRATED POWER UNIT

- Eliminates GSE
- 6.3 Program Complete FY00-02



## ELECTRIC ACTUATION

- Eliminates Centralized Hydraulics
- High HP, Low Cost Stabilator Hardware FY02-04

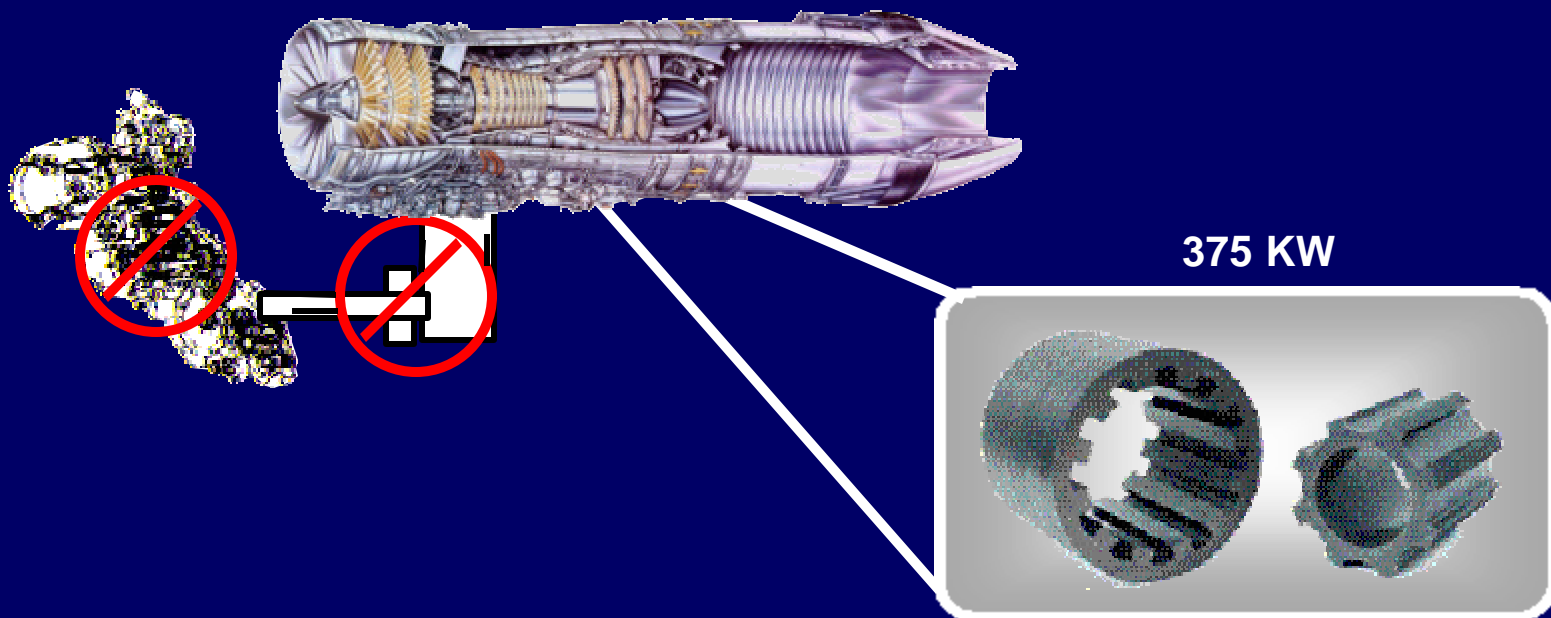




# Revolutionary Internal Engine Starter / Generator



- **INTERNAL F110 ENGINE ELECTRICAL STARTER AND GENERATOR PRELIMINARY DESIGN COMPLETED**



- **ELIMINATES ENGINE GEARBOXES - HUGE REDUCTION IN PARTS**
- **REPLACE WITH SINGLE COMPONENT - SOLID ROTOR ELECTRIC MACHINE**
- **COMBINES STARTER AND GENERATOR FUNCTIONS**
- **REDUCES FRONTAL AREA**



# Internal Starter / Generator (IS/G)



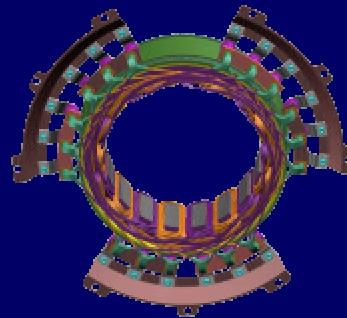
## Aircraft Main Power

- IS/G benefits both manned & unmanned aircraft and is part of IHPTET Phase III

Work with outside organizations for magnetic materials research (DARPA & AFOSR)

Collaborate with IHPTET organizations for engine integration and testing

Develop related technologies necessary to meet Gen II goals



- 550-600°C Mag Materials
- 400°C Insulation
- 1.5kW/#
- >15,000 Hrs MTBF







# Integrated Power Unit (IPU)



## Auxiliary/Emergency Power

- IPU has significant payoff for reduced supportability



6.2

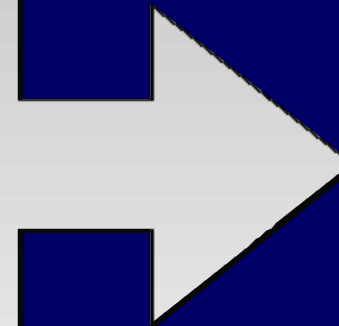


6.3



Dual-Use

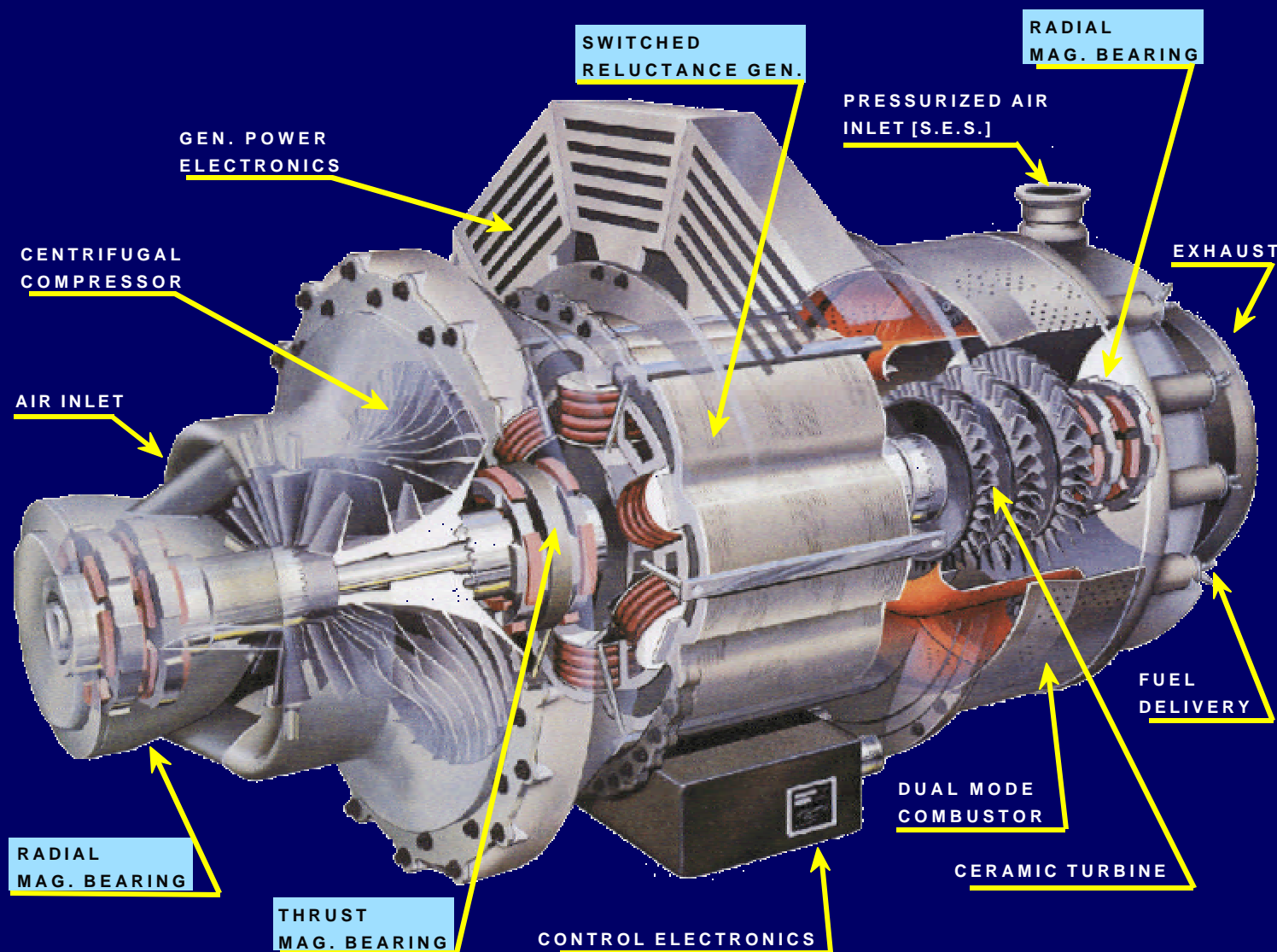
- Component development (SR starter/generator & high speed magnetic bearings)
- Model integration of rotor dynamics, electrical & controls
- Integrate SR machine and magnetic bearings on one rotor
- Couple SRM/magnetic bearings with existing turbomachine
- Improve controls, electronics and SR machine for reliability & life



- 5000 Hrs MTBF
- 400 HP/ft<sup>3</sup>
- 550-600°C Mag Materials



# More Electric Aircraft Integrated Power Unit



**CONTRACTOR:**  
ALLIED SIGNAL / AVCON



# Switched Reluctance Motor (SRM) Design Issues



## SRM Cooling Requirements

- Heat transfer coefficients
- Windage losses
- Magnetic losses
- Axial conduction

## Stator Integrity

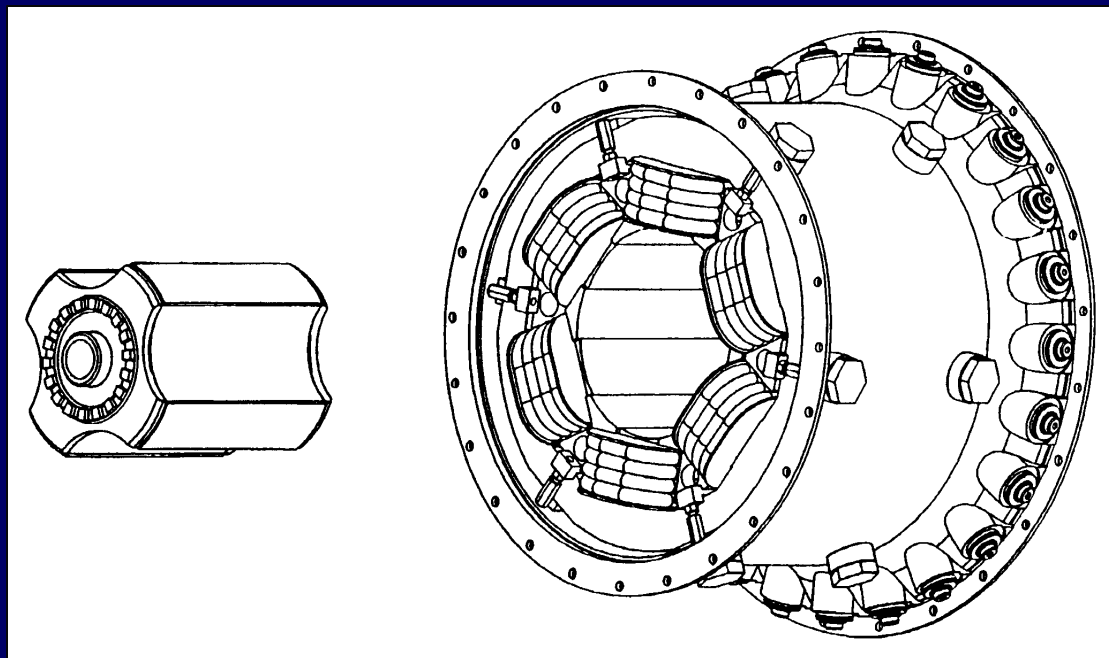
- Temperature distribution
- Impregnation

## Stator Winding

- Temperatures
- Frequency

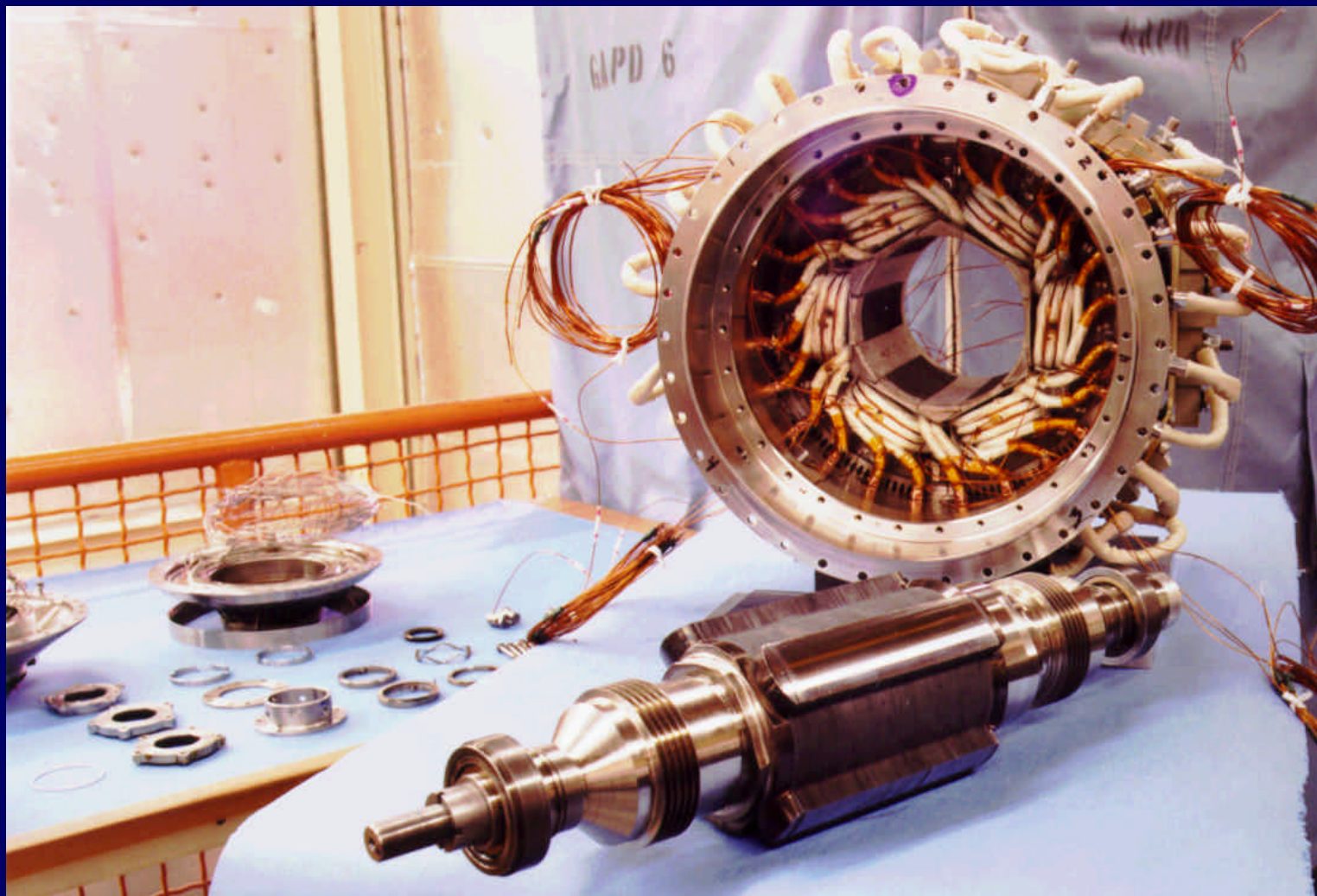
## Rotor Integrity

- Temperature distribution
- Tip speed
- Material properties
- Life prediction
- Laminate Stiffness





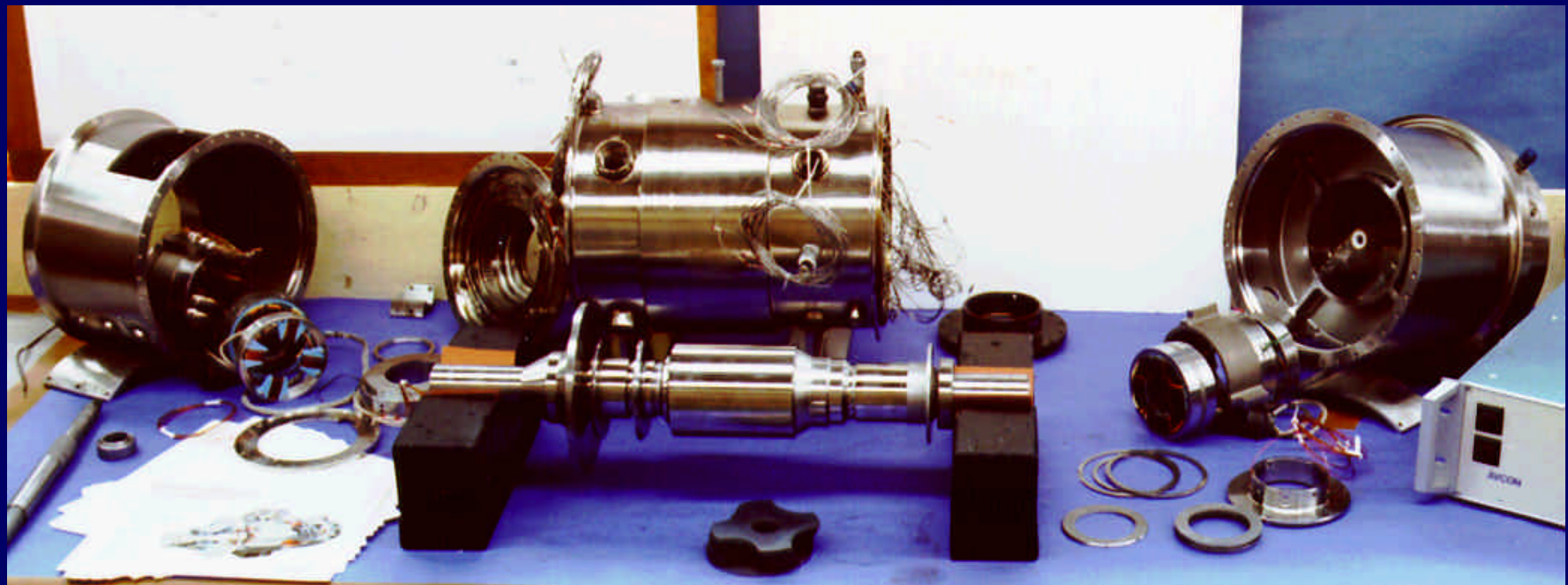
# MEA IPU SRM Subsystem Test Rig (Rotor & Stator)







# MEA IPU Rotor / Bearing Subsystem Test Rig/Rig Disassembled







# Magnetic Bearings

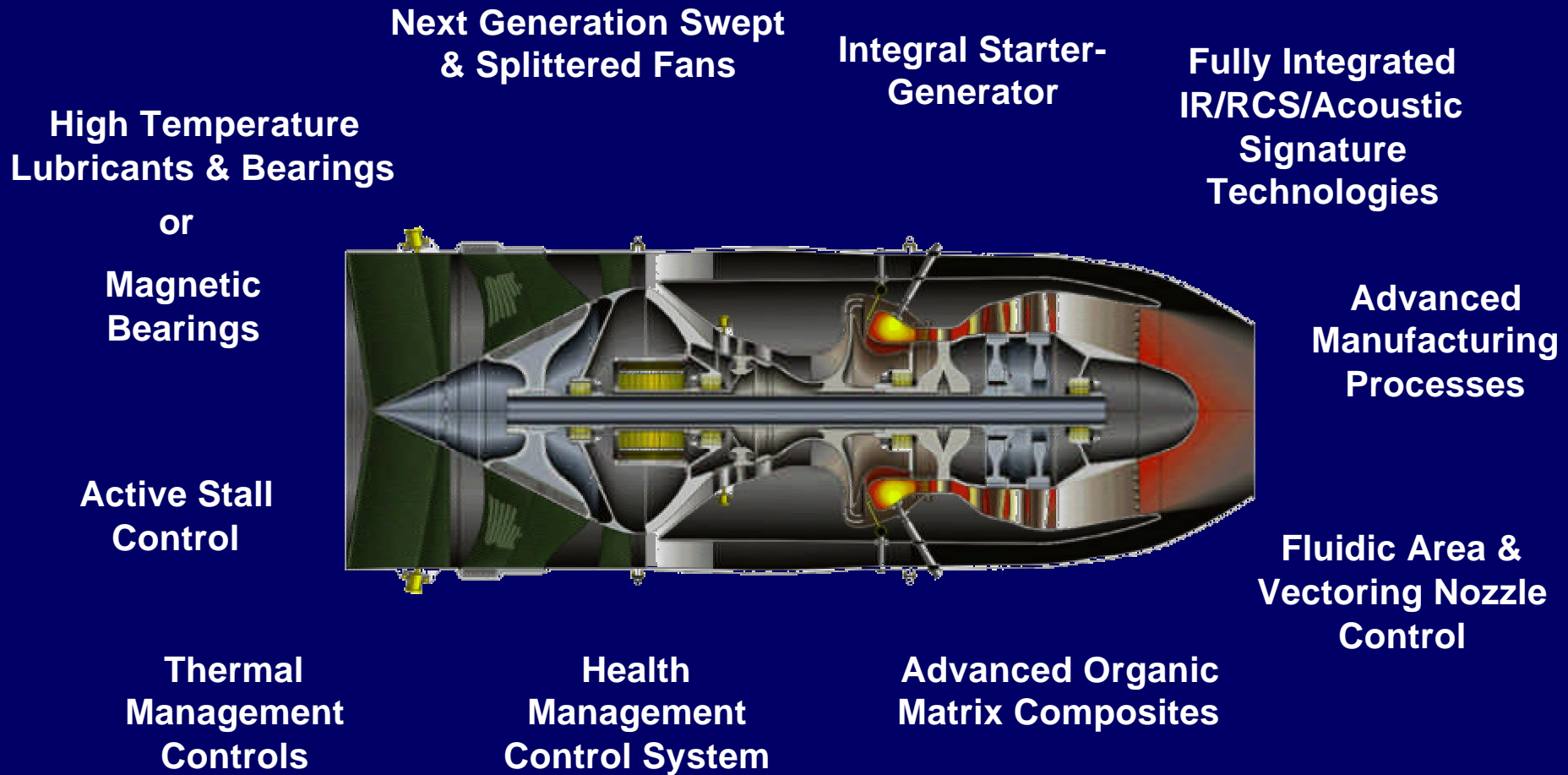


- **Electromagnetic biased bearing**
  - Heavy/high power consumption
  - High temperature capable
- **Permanent magnet biased bearing**
  - Lower weight/ lower power
  - Smaller than electromagnetic bearings
  - Temperature limited





# UAV Technologies

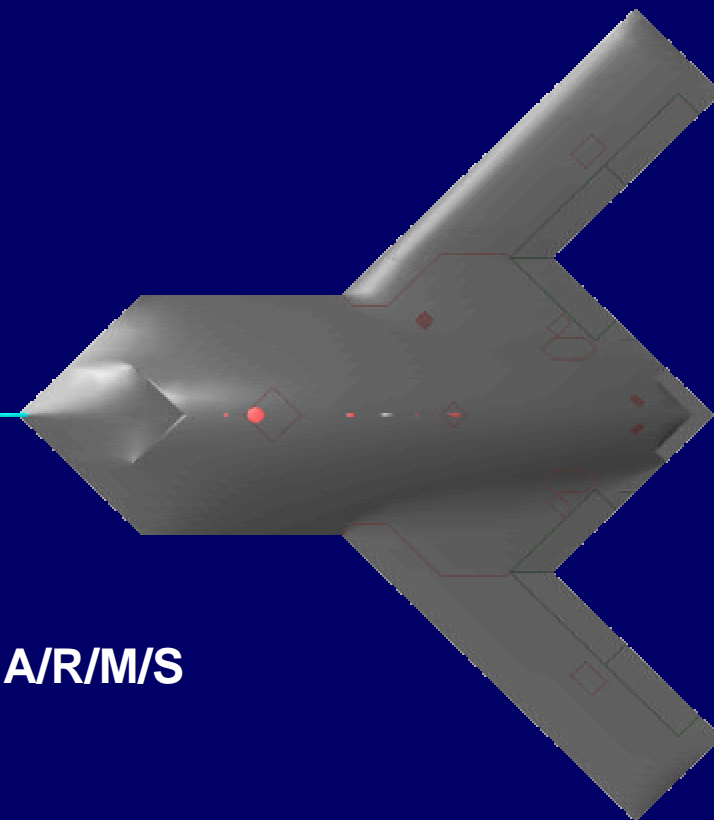




# Unmanned Combat Air Vehicle (UCAV)



- **Integral Part of US Force Structure by 2010**
  - Clean Sheet Designs
  - Increased Tactical Deterrence
  - Reduced Life-Cycle Costs (50%-80%)
- **High Speed Starter/Generator Systems are Likely (Internal to main propulsion engine)**
- **Totally Lubeless/Oilless Aircraft for Improved A/R/M/S and Long Term Storability**
  - Electromechanical Actuation
  - Air-Only Cooling
  - Electric Secondary Power System





# Power Technologies Enable Directed Energy ...



## PROPULSION DIRECTORATE

## OTHER DIRECTORATE

## APPLICATION

LOW  
POWER

**BATTERIES**

**CAPACITORS**

**ADV. SENSORS (AFRL/SN)**

**REVOLUTIONARY  
SENSORS**

"MID"  
POWER

**IPU**

**LASER**

**IIS/G**

**HPM**

**(AFRL/DE)**

**HPM UCAV**

HIGH  
POWER

**HTSC  
GENERATORS**

**PMAD**

**ADVANCED  
LASER**

**ADVANCED  
HPM**

**(AFRL/DE)**

**ADVANCED  
TURBINES**

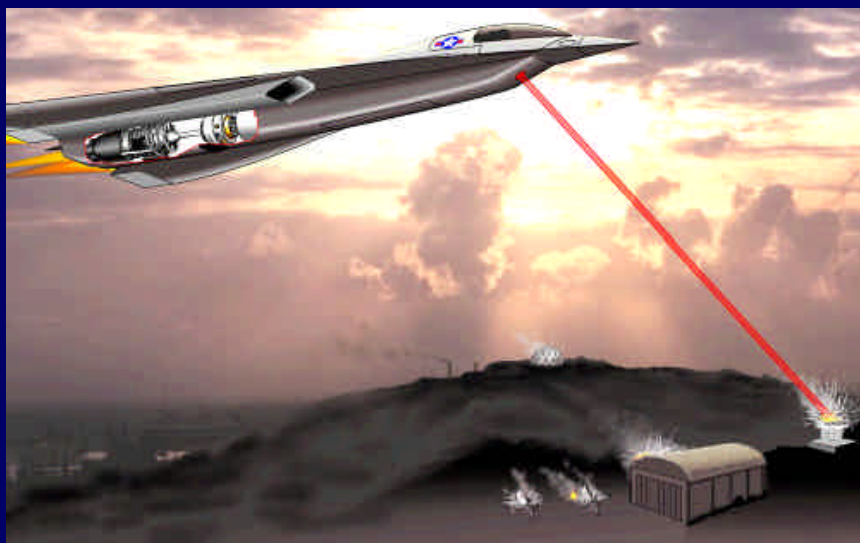
**HYPER-  
SONICS**

**LETHAL**

**NON-  
LETHAL**



# Directed Energy Weapons (DEW)

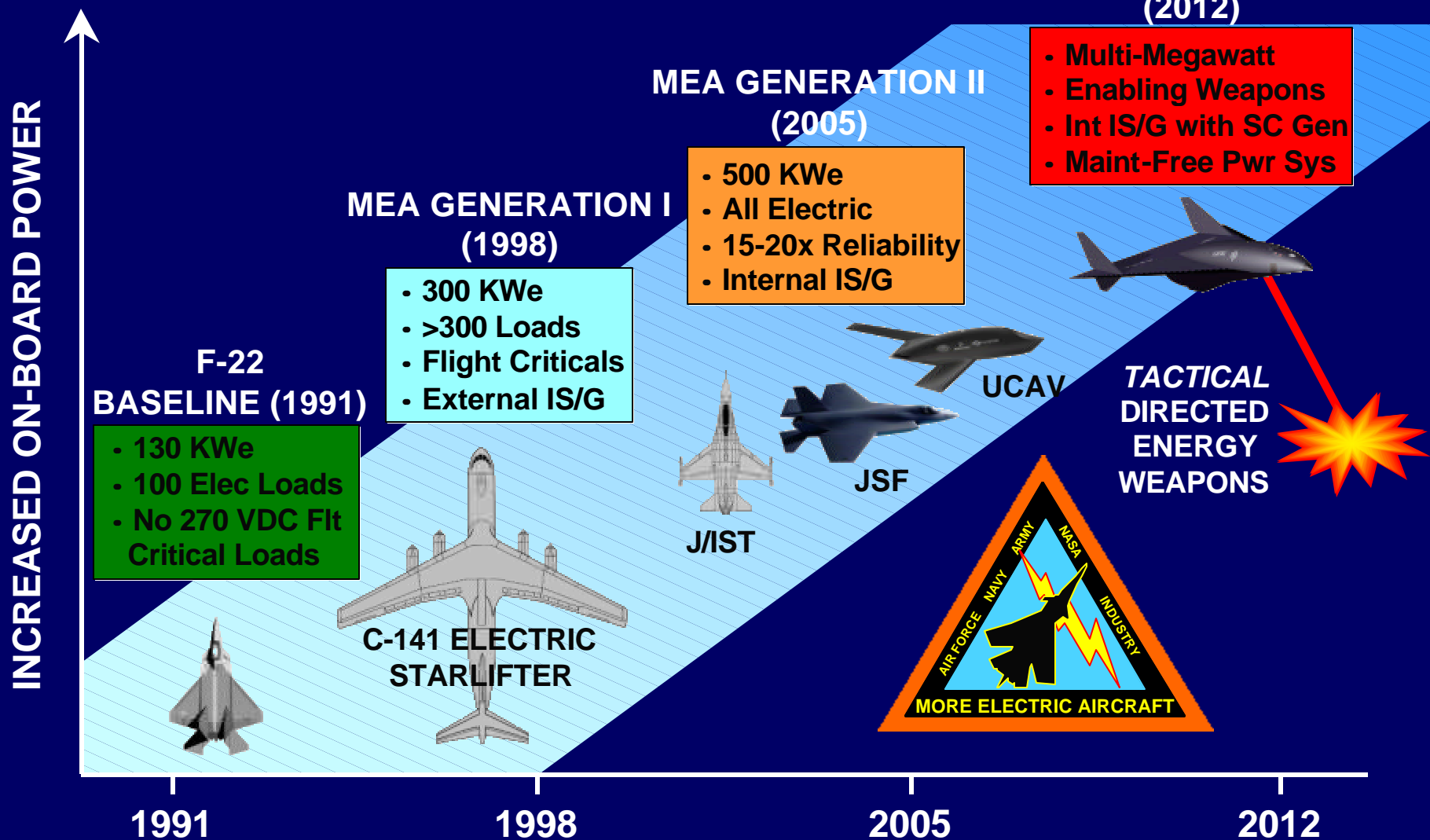


- Ground, Sea, and Air Platforms
  - Projected to Totally Eliminate the need for Conventional Weapons by 2030
  - Require High Power Light-Weight Energy Sources
- 
- Critical Technology Areas Include:
    - Increased Electric Power Generation and Storage
    - Self Starting Capabilities
    - High Speed Magnetic Bearings
    - Air Only Cooling





# Aircraft Power Capabilities





# Bottom Line



## ROTOR APPLICATION (SOFT MAGNETIC MATERIAL)

OPERATING TEMPERATURE	—————▶	600°C For 5000 Hours
MACHINE CORE LOSS	—————▶	60% Reduction From SOA Or < 480 W/Kg @ 5000Hz, 2 T, 500°C
YIELD STRENGTH	—————▶	700 MPa @ 500°C; 825 MPa 300°C
ROTOR CREEP RATE (@ 550°C & 600 MPa)	—————▶	$2 \times 10^{-6} \text{ hr}^{-1}$ for 5000 hours
RESISTIVITY	—————▶	40 --> 60 micro-ohm-cm @ RT

## BEARING APPLICATION (HARD MAGNETIC MATERIAL)

OPERATING TEMPERATURE	—————▶	450°C for 5000 Hours
ENERGY PRODUCT	—————▶	30MGOe @ 450°C
RESISTIVITY	—————▶	60 --> 120 micro-ohm-cm @ RT



# Summary



**Today's systems are typically engineered around magnetic material temperature limitations.**

**Higher operating temperature magnets enable simpler, more efficient designs for many commercial and military applications.**

**As commercial and military electromechanical applications continue to evolve power system requirements continue to become more extreme.**

**New magnetic material systems are crucial to enable advanced power generation, distribution, and utilization systems.**

